AD-A054 327

AD-A 054 327

AD

MEMORANDUM REPORT ARBRL-MR-02823

DERIVATION OF CONDITIONAL KILL PROBABILITIES FOR PROPELLANT-FILLED CARTRIDGE CASES SUBJECT TO FRAGMENT ATTACK

Ann Sutphin Hafer
Michael B. Danish

April 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER MEMORANDUM REPORT ARBRL-MR-02823	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Derivation of Conditional Kill Probabilities for Propellant-Filled Cartridge Cases Subject to Fragment Attack		5. TYPE OF REPORT & PERIOD COVERED Final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ann Sutphin Hafer Michael B. Danish		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Ballistic Research Laboratory (ATTN: DRDAR-BLV) Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L662618AH80
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Armament Research & Development Command U. S. Army Ballistic Research Laboratory (ATTN: DRDAR-BL) Aberdeen Proving Ground, MD 21005		12. REPORT DATE APRIL 1978 13. NUMBER OF PAGES 40
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cartridge Cases
Kill Probabilities
Vulnerability
Fragments

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method of deriving conditional kill probabilities for fragment attack of propellant-filled cartridge cases is presented. Previous experimental test firings yielded reaction probabilities for various levels of fragment striking speeds. A new kill criterion was constructed as a function of residual fragment speed after cartridge case perforation. The kill criterion was incorporated in a vulnerability code and average kill probabilities for various striking mass/speed combinations were produced. From these data, equations expressing conditional kill probability as a function of striking mass and striking speed were generated.

TABLE OF CONTENTS

I. INTRODUCTION

The vulnerability of ammunition to fragment attack is an important factor in vulnerability analysis, because targets such as tanks, armored personnel carriers, and self-propelled guns all contain stowed ammunition. Should the ammunition burn or deflagrate inside the vehicle, a catastrophic kill would most likely occur, given current ammunition stowage techniques. Since ammunition survivability is so critical to the survival of the crew and vehicle, a more detailed treatment of the ammunition conditional kill probabilities than is afforded by the standard $P_{K/H}$ methodology[1] was considered worthwhile.

The $P_{K/H}$ methodology specifies the kill criterion for a critical component in terms of the minimum hole size in the sensitive region which a striking fragment must make after perforating whatever inert layers there may be on the component, exterior to the sensitive region. As applied to a cartridge case filled with propellant, this criterion requires estimating the minimum residual mass, after perforation of the case itself, which will ignite the propellant. (Mass can be related to hole size by a "shape factor"). Attacks are considered from six aspects around the component (top, bottom, right, left, front, back)at two incidence angles, 0 and 45 degrees. For several reasons, an approach other than the $P_{K/H}$ program seemed appropriate. For an approximately cylindrical cartridge case, three of the aspects would yield no additional information. Secondly, two incidence angles were considered insufficient to represent the possible attack conditions. Thirdly, no reliable data existed from which a minimum mass could be estimated.

Of particular interest are 100 mm rounds found in a Soviet tank attacked by the XM70 scatterable mine. This mine projects a dense spray of potentially lethal fragments over a wide area inside the vehicle. It is expected that many of these fragments are capable of perforating the cartridge case and igniting the propellant in stowed ammunition.

II. PROCEDURE

The New Mexico Institute of Mining and Technology (NMI) compiled data[2] from various sources in which fragments were fired at US and Soviet cartridge cases filled with propellant. The probability of a

---

1 *Loren R. Kruse and Paul L. Brizzolara, "An Analytical Method for Deriving Conditional Probabilities of Kill for Target Components", Ballistic Research Laboratories Report No. 1563, December 1971.* (AD #891805L).

2 *David L. Collis, James J. Forster, and John P. McLain, "Vulnerability of Propellant-Filled Munitions to Impact by Steel Fragments", New Mexico Institute of Mining and Technology, TERA Group, Socorro, New Mexico, Ballistic Research Laboratories Contract Report No. 65, March 1972.* (AD #893651L)

burning reaction (either slow or violent) was characterized as a cumulative normal function of fragment striking speed, given a particular mass. A convenient parameter for comparing burn probability functions for various cartridge cases, propellants, striking masses, etc. is the threshold velocity or V_{50}. This is the striking velocity at which 50 percent of the fragments are expected to cause a burn. No consistent variation in V_{50} was observed when any of the following conditions were varied: cartridge case type, propellant type, propellant geometry (single or multi-perforated), fragment temperature, or fragment incidence angle relative to the longitudinal axis of the case. The V_{50} did exhibit a marked dependence on fragment mass, decreasing as mass increased. Though only a few shots were available against Soviet cases, NMI noted that the V_{50} for Soviet cases was about 300 m/s higher than for US cases. We observed that the perforation ballistic limit velocity was approximately 300 m/s greater for the Soviet cases than for the US cases. From this we concluded that the most important difference between the Soviet and US rounds was in the case thickness and that differences in propellant characteristics made a negligible contribution.

The Soviet case used in the NMI tests was a 100mm round; however, it is unrepresentative of most Soviet 100mm cases. First, in all the NMI experimental rounds the propellant grains were poured directly into the case. Some Soviet cases contain an interior liner between the propellant grains and the case wall. One such liner is 95 percent wax and 5 percent paper. Second, the case thickness was not typical.

The first variation, the lack of a liner, could not be addressed with the available data. The consequence is that our model may predict greater ammunition vulnerability than should be expected.

The second variation, case thickness, was handled in the following manner. We combined all available data, in addition to the ten shots against Soviet cases, and defined the burn criterion in terms of residual speed rather than striking speed. This greatly enlarged our sample size, a requirement for modeling probabilistic phenomena, and it made the burn probability less dependent on case thickness and material. We assumed a cumulative normal relationship between burn or kill probability and residual speed. We then applied a probit analysis[3] to obtain the necessary parameters to the cumulative normal function. Results of the probit analysis are presented in Appendix A.

3 *Mary Gibbons Natrella, Experimental Statistics, Reprint of the Experimental Statistics Portion of the AMC Handbook, National Bureau of Standards Handbook No. 91, August 1963.*

The next step was to apply the kill criterion to the two cartridge cases of interest. Combinatorial Geometry descriptions[4] of the cartridge cases were prepared (see Appendix B). Shotlines were traced through an array of hit locations on each case. A vulnerable area code[5] evaluated several combinations of striking mass and speed at each hit location with the new kill criterion to determine the probability of kill (burn) when the cartridge cases are subjected to fragment attack. The kill probability results are presented in Appendix C. Lastly, the mass/speed/kill probability data were input to the regression sections of the $P_{K/H}$ program which yielded generalized equations for conditional kill probabilities as functions of fragment striking mass and speed. The final $P_{K/H}$ equations for each cartridge case are presented in Appendix D.

III. CONCLUSIONS

We now have a procedure for generating conditional kill probabilities for fragments attacking propellant-filled munitions which can be applied to a wide spectrum of cartridge case designs and which is based on actual test firing. This is considered an improvement over the standard $P_{K/H}$ approach because all incidence angles from 0 degrees to grazing impact have been included in the analysis, rather than only 0 and 45 degrees.

ACKNOWLEDGEMENT

The authors wish to acknowledge the contribution of Mr. Larry Losie of Falcon Research and Development, who programmed the exact probit solution on a Wang 720 programmable desk calculator.

---

4 *Lawrence W. Bain, Jr. and Mathew J. Reisinger, "The GIFT Code User Manual; Volume I. Introduction and Input Requirements", Ballistic Research Laboratories Report No. 1802, July 1975.* (AD #B006037L)

5 *Calvin Candland, Gary Kuehl, B.E. Cummings, "A Survey of Models Used Within the Vulnerability Laboratory - Circa 1973", Ballistic Research Laboratories Memorandum Report No. 2435, January 1975 (see section entitled Vulnerable Area, VAREA).* (AD #B001871L)

Appendix A. Derivation of New Kill (Burn) Criterion

The NMI data presented in Table A-1 of Reference 2 consist of impact speeds and reactions (none, burning, or violent) for several combinations of striking mass, incidence angle relative to the case longitudinal axis, cartridge case type, and propellant type. Using THOR equations for residual speed[6] we converted impact speeds to residual speeds. All residual speeds were rounded off to the nearest 100 m/s. Data for each striking mass were handled separately; however, data from various cartridge cases and propellants and for incidence angles of 0 and 45 degrees were combined.

Our probit solution assumes that the probability of reaction can be described as a cumulative normal function of the level of stimulus, or the residual speed in our problem:

$$P(V_{res}) = 1/(\sqrt{2\pi}\ \sigma) \int_{-\infty}^{V_{res}} \exp(-(V - Vr_{50})^2/2\sigma^2)\ dV \qquad \text{A-1}$$

where Vr_{50} and σ are parameters to be derived from the probit solution.

One relates the observed burn probability (number of reactions divided by number of trials at a given level of stimulus) to the standard normal variable, z, which would yield such a probability as follows:

$$P_{observed} \equiv P(z) = 1/\sqrt{2\pi} \int_{-\infty}^{z} \exp(-u^2\ /2)\ du \qquad \text{A-2}$$

Given P(z), one can find z. If the cumulative normal function is a good description of the probability of reaction, z should be linearly related to the level of stimulus, or the residual speed:

$$z = (V_{res} - Vr_{50})/\sigma$$

A linear regression of the z's corresponding to the observed probabilities of reaction against the levels of stimulus which produced the reaction will yield the parameters Vr_{50} and σ. This is the graphical probit method. We carried the solution one step further by performing one iteration of the "exact" or computational method. Table A-1 summerizes the results of the exact probit solution.

---

6 *"The Resistance of Various Metallic Materials to Perforation by Steel Fragments: Empirical Relationships for Fragment Residual Velocity and Residual Weight", Ballistic Analysis Laboratory, Institute for Co-operative Research, The Johns Hopkins University, Project THOR Technical Report 47, April 1961.*

Since the number of trials with the 0.65 and 3.89 gram fragments were so small compared to those with the 0.32 and 0.97 gram fragments, less significance was attached to the former results than to the latter. Values of Vr_{50} for the 0.32 and 0.97 gram fragments were virtually identical; therefore, averages of the Vr_{50}'s and σ's for these two masses were considered the most representative values of the parameters required in Equation A-1.

Table A-I. Probit Solution Parameters for Various Fragment Masses

Mass (gm)	Vr_{50} (m/s)	σ (m/s)	Number of Trials
0.32	444	463	296
0.65	554	242	19
0.97	443	541	329
3.89	681	277	8

Appendix B. Combinatorial Geometry Model of Cartridge Cases

Two cartridge cases were modeled by the Combinatorial Geometry technique. Each represented a 100 mm round. (We assumed the warhead was invulnerable to fragment attack: the warhead end of the cartridge case was represented by an impenetrable cap.) The first cartridge case is a model of a mild steel case whose wall thickness is about 1.9 mm (0.074 inch) thick. This case will be referred to as the V500 ammo. The other represents a brass case whose wall thickness is about 2.5 mm (0.10 inch). This is called the V600 ammo. Residual mass and speed equations are not available for cartridge case brass, so mild steel equations were used to degrade fragments perforating this case as well as the V500 case. Figure B-1 shows a side view of the solids comprising the Combinatorial Geometry model of each case. The radii of solids 3, 5, and 7 are smaller for the thicker-walled V600 case. Tables B-I and B-II present the Description of Solids for the V500 and V600 ammo, respectively. Tables B-III and B-IV present the Region Combination Data and the Identification Table, respectively, which are identical for each cartridge case.

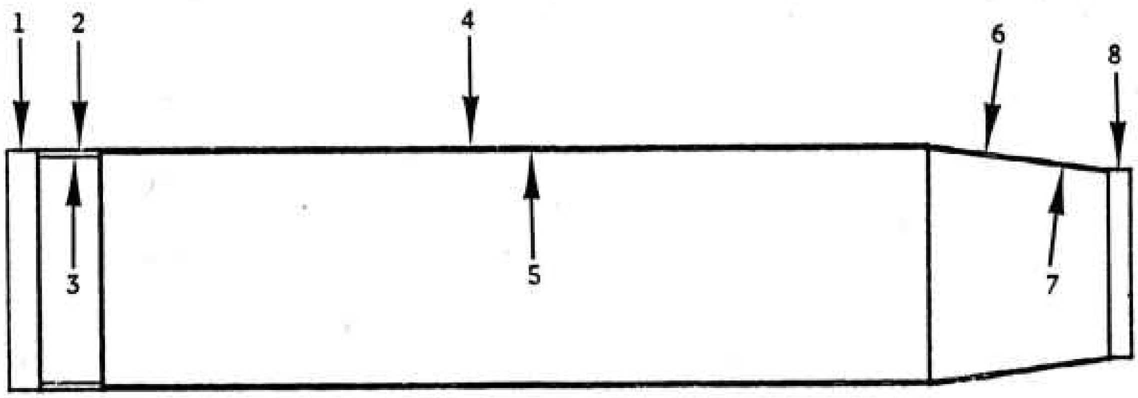

Figure B-1. Solids in the Combinatorial Geometry Model of Cartridge Cases.

Table B-I. Description of Solids for V500 Ammo (mm)

Solid	Type	Solid Data						Remarks
1	RCC	0. 67.31	0.	0.	0.	0.	17.78	Base
2	RCC	0. 67.31	0.	17.78	0.	0.	35.56	Lower cylinder (outer)
3	RCC	0. 63.5508	0.	17.78	0.	0.	35.56	Lower cylinder (inner)
4	RCC	0. 67.31	0.	53.34	0.	0.	469.9	Main cylinder (outer)
5	RCC	0. 65.4304	0.	53.34	0.	0.	469.9	Main cylinder (inner)
6	TRC	0. 67.31	0. 53.34	523.24	0.	0.	101.6	Taper (outer)
7	TRC	0. 65.4896	0. 51.5196	523.24	0.	0.	101.6	Taper (inner)
8	RCC	0. 53.34	0.	624.84	0.	0.	12.7	Impenetrable cap

Table B-II. Description of Solids for the V600 Ammo (mm)

Solid	Type	Solid Data						Remarks
1	RCC	0. 67.31	0.	0.	0.	0.	17.78	Base
2	RCC	0. 67.31	0.	17.78	0.	0.	35.56	Lower cylinder (outer)
3	RCC	0. 60.198	0.	17.78	0.	0.	35.56	Lower cylinder (inner)
4	RCC	0. 67.31	0.	53.34	0.	0.	469.9	Main cylinder (outer)
5	RCC	0. 64.77	0.	53.34	0.	0.	469.9	Main cylinder (inner)
6	TRC	0. 67.31	0. 53.34	523.24	0.	0.	101.6	Taper (outer)
7	TRC	0. 65.0794	0. 51.0194	523.24	0.	0.	101.6	Taper (inner)
8	RCC	0. 53.34	0.	624.84	0.	0.	12.7	Impenetrable cap

Table B-III. Region Combination Data for V500 and V600 Ammo

Region	Solids	
1	1	
2	2	-3
3	3	
4	4	-5
5	5	
6	6	-7
7	7	
8	8	

Table B-IV. Identification Table for V500 and V500 Ammo

Region	Item	
1	1001	Base
2	1002	Lower cylinder outside
3	1003	Lower cylinder inside
4	1004	Main cylinder outside
5	1005	Main cylinder inside
6	1006	Taper outside
7	1007	Taper inside
8	1008	Impenetrable cap

Appendix C. Analytical Evaluation of Average Kill Probabilities for Various Striking Mass and Speed Combinations

We wise to apply the new burn criterion (Equation A-1) to a set of representative attack configurations for fragments against the two cartridge cases modeled in Appendix B. The $P_{K/H}$ program considers only two incidence angles relative to the case surface, 0 and 45 degrees. This was considered inadequate for our purposes. Therefore, shotlines were traced at a randomly chosen point in every 25.4 mm square cell on a grid plane which was overlaid on the target. The shotlines were perpendicular to the grid plane. Several orientations of the grid plane were considered; the plane made angles of 0, ±30, ±60, and ±90 degrees relative to the case diameter. Several mass and speed combinations were traced along each shotline. The residual speed was inserted in the burn criterion to determine the kill (or burn) probability for that shotline and the particular striking mass/speed combination under consideration. The THOR fragment penetration equations predict an increasing fragment mass loss with increasing fragment speed. This is because the empirical data base upon which the equations are based included the residual mass of only the largest single perforating fragment. Additional pieces of the residual penetrator were ignored. This procedure meant that our cartridge case kill probabilities for a given mass peaked at a certain fragment speed, then declined. However, the propellant is impacted by all these residual fragments, not just the largest single one. Therefore, we felt it more realistic to level off the kill probabilities at the peak rather than accept a declining kill probability with increasing fragment speed. For the grid plane at +90 degrees, every mass/speed combination yielded a zero kill probability. Tables C-I through C-XII present average kill probabilities for the mass/speed combinations at the grid plane angles of 0, ±30, ±60, and -90 degrees for the V500 and the V600 Ammo.

The final conditional kill probabilities must be independent of the grid plane angle, so the results presented in Tables C-I through C-XII were averaged over all angles. Since much less of the spherical area around the case is available for attacks from ±90 degrees, results for these angles were weighted less than those from the other angles. Experience has shown that a reasonable approximation to the correct weights is to weight all angles other than ±90 degrees by eight and to weight ±90 degrees by unity. Results of this procedure are given in Tables C-XIII and C-XIV, which present weighted kill probabilities for each mass/speed combination for the V500 and V600 ammo cases, respectively. A fragment shape factor (see Appendix D) of 57.98 $cm^2/kg^{2/3}$ was used in the penetration equations that were utilized in the generation of the kill probabilities given in Tables C-I through C-XIV.

Table C-I. Kill Probabilities for the V500 Ammunition at 0 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.07	.07	.07	.07	.07
0.32	.00	.00	.00	.05	.19	.35	.35	.35	.35
0.65	.00	.00	.02	.19	.35	.50	.62	.62	.62
0.97	.00	.00	.10	.26	.43	.58	.68	.71	.71
1.94	.00	.00	.20	.38	.55	.68	.77	.79	.80
3.89	.00	.13	.30	.48	.65	.76	.83	.86	.87
7.78	.00	.19	.38	.57	.73	.82	.87	.89	.89
15.55	.05	.26	.46	.65	.78	.85	.91	.93	.94
32.40	.12	.31	.53	.71	.83	.90	.94	.96	.97

Table C-II. Kill Probabilities for the V500 Ammunition at 30 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.01	.01	.01	.01	.01
0.32	.00	.00	.00	.00	.09	.22	.22	.22	.22
0.65	.00	.00	.00	.11	.24	.35	.53	.53	.53
0.97	.00	.00	.02	.17	.31	.48	.61	.64	.64
1.94	.00	.00	.14	.28	.46	.61	.72	.76	.76
3.89	.00	.06	.22	.41	.58	.17	.80	.85	.85
7.78	.00	.14	.32	.51	.68	.79	.86	.89	.89
15.55	.00	.21	.41	.61	.76	.84	.88	.90	.91
32.40	.09	.28	.49	.68	.81	.87	.90	.91	.91

Table C-III. Kill Probabilities for the V500 Ammunition at 60 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.65	.00	.00	.00	.00	.00	.02	.04	.04	.04
0.97	.00	.00	.00	.00	.01	.04	.14	.14	.14
1.94	.00	.00	.00	.01	.07	.18	.30	.37	.37
3.89	.00	.00	.01	.08	.20	.34	.47	.56	.56
7.78	.00	.00	.04	.19	.34	.48	.60	.68	.69
15.55	.00	.02	.15	.30	.47	.60	.69	.74	.75
32.40	.00	.09	.25	.42	.57	.68	.74	.77	.78

Table C-IV. Kill Probabilities for the V500 Ammunition at -30 Degrees for Various Combinations of Striking Mass and Speed

Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.07	.19	.19	.19	.19
0.65	.00	.00	.00	.09	.21	.36	.49	.49	.49
0.97	.00	.00	.00	.15	.29	.45	.58	.60	.60
1.94	.00	.00	.12	.26	.43	.58	.68	.72	.72
3.89	.00	.05	.21	.38	.55	.67	.75	.79	.79
7.78	.00	.13	.30	.48	.64	.75	.81	.84	.84
15.55	.00	.20	.38	.57	.71	.80	.84	.87	.87
32.40	.08	.26	.46	.64	.77	.84	.87	.88	.88

Table C-V. Kill Probabilities for the V500 Ammunition at -60 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.65	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.97	.00	.00	.00	.00	.00	.00	.08	.08	.08
1.94	.00	.00	.00	.00	.03	.12	.23	.29	.29
3.89	.00	.00	.00	.05	.14	.27	.40	.50	.50
7.78	.00	.00	.02	.14	.28	.41	.54	.62	.63
15.55	.00	.00	.11	.25	.41	.54	.64	.69	.70
32.40	.00	.07	.20	.37	.52	.63	.69	.72	.73

Table C-VI. Kill Probabilities for the V500 Ammunition at -90 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.65	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.97	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.94	.00	.00	.00	.00	.00	.00	.00	.00	.00
3.89	.00	.00	.00	.00	.00	.00	.00	.00	.00
7.78	.00	.00	.00	.00	.00	.00	.00	.00	.00
15.55	.00	.00	.00	.00	.00	.00	.00	.00	.00
32.40	.00	.00	.00	.00	.00	.23	.43	.63	.63

Table C-VII. Kill Probabilities for the V600 Ammunition at 0 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	917	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.02	.16	.16	.16	.16
0.65	.00	.00	.00	.05	.19	.33	.47	.47	.47
0.97	.00	.00	.00	.13	.28	.43	.56	.57	.57
1.94	.00	.00	.10	.25	.42	.56	.66	.70	.70
3.89	.00	.01	.20	.37	.53	.66	.75	.78	.79
7.78	.00	.12	.29	.46	.63	.74	.81	.85	.85
15.55	.00	.19	.37	.56	.71	.80	.85	.88	.88
32.40	.06	.26	.45	.64	.77	.84	.88	.89	.89

Table C-VIII. Kill Probabilities for the V600 Ammunition at 30 Degrees for Various Combinations of Striking Mass and Speed

Mass	Speed (m/s) 305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.01	.03	.03	.03	.03
0.65	.00	.00	.00	.01	.08	.22	.34	.34	.34
0.97	.00	.00	.00	.02	.17	.31	.45	.45	.45
9.94	.00	.00	.02	.17	.31	.47	.59	.64	.64
3.89	.00	.00	.13	.28	.45	.59	.69	.74	.74
7.78	.00	.06	.21	.40	.56	.69	.78	.83	.83
15.55	.00	.14	.32	.49	.66	.77	.84	.87	.88
32.40	.01	.21	.40	.59	.74	.83	.87	.89	.89

Table C-IX. Kill Probabilities for the V600 Ammunition at 60 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.65	.00	.00	.00	.00	.00	.00	.01	.01	.01
0.97	.00	.00	.00	.00	.00	.01	.04	.04	.04
1.94	.00	.00	.00	.00	.02	.05	.14	.15	.15
3.89	.00	.00	.00	.02	.05	.18	.30	.40	.40
7.78	.00	.00	.01	.07	.20	.33	.47	.57	.57
15.55	.00	.00	.03	.19	.33	.48	.59	.67	.68
32.40	.00	.02	.16	.31	.47	.59	.68	.73	.75

Table C-X. Kill Probabilities for the V600 Ammunition at -30 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.65	.00	.00	.00	.00	.06	.19	.30	.30	.30
0.97	.00	.00	.00	.00	.15	.28	.42	.42	.42
1.94	.00	.00	.00	.14	.28	.44	.56	.61	.61
3.89	.00	.00	.12	.25	.42	.56	.66	.71	.71
7.78	.00	.04	.20	.38	.53	.66	.74	.79	.80
15.55	.00	.13	.30	.47	.63	.73	.80	.83	.84
32.40	.00	.20	.38	.56	.70	.79	.83	.85	.86

Table C-XI. Kill Probabilities for the V600 Ammunition at -60 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.65	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.97	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.94	.00	.00	.00	.00	.00	.00	.07	.07	.07
3.89	.00	.00	.00	.00	.00	.11	.23	.31	.31
7.78	.00	.00	.00	.02	.14	.26	.40	.50	.50
15.55	.00	.00	.00	.13	.27	.41	.53	.61	.63
32.40	.00	.00	.11	.26	.41	.54	.63	.68	.70

Table C-XII. Kill Probabilities for the V600 Ammunition at -90 Degrees for Various Combinations of Striking Mass and Speed

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.65	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.97	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.94	.00	.00	.00	.00	.00	.00	.00	.00	.00
3.89	.00	.00	.00	.00	.00	.00	.00	.00	.00
7.78	.00	.00	.00	.00	.00	.00	.00	.00	.00
15.55	.00	.00	.00	.00	.00	.00	.00	.00	.00
32.40	.00	.00	.00	.00	.00	.20	.37	.54	.54

Table C-XIII. Average Kill Probabilities for Various Striking Mass and Speed Combinations Against the V500 Ammunition

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.02	.02	.02	.02	.02
0.32	.00	.00	.00	.01	.07	.14	.14	.14	.14
0.65	.00	.00	.00	.07	.15	.24	.32	.32	.32
0.97	.00	.00	.02	.11	.20	.29	.40	.41	.41
1.94	.00	.00	.09	.18	.29	.41	.52	.56	.56
3.89	.00	.05	.14	.27	.40	.53	.62	.68	.68
7.78	.00	.09	.20	.36	.51	.62	.70	.75	.75
15.55	.01	.13	.29	.45	.60	.69	.75	.79	.80
32.40	.06	.19	.37	.54	.67	.75	.80	.82	.83

Table C-XIV. Average Kill Probabilities for Various Striking Mass and Speed Combinations Against the V600 Ammunition

	Speed (m/s)								
Mass	305	610	914	1219	1524	1829	2134	2438	2743
0.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.19	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.32	.00	.00	.00	.00	.00	.04	.04	.04	.04
0.65	.00	.00	.00	.01	.06	.14	.21	.21	.21
0.97	.00	.00	.00	.03	.11	.20	.28	.28	.28
1.94	.00	.00	.02	.11	.20	.29	.39	.41	.41
3.89	.00	.00	.09	.18	.28	.40	.50	.56	.56
7.78	.00	.04	.14	.25	.39	.51	.61	.67	.68
15.55	.00	.09	.19	.35	.49	.61	.69	.74	.75
32.40	.01	.13	.29	.45	.59	.69	.75	.78	.79

Appendix D. Conditional Kill Probability Equations

Conditional kill probabilities as functions of fragment mass, average presented area, and striking speed were generated using the MAXFIT and GENREG subroutines of the $P_{K/H}$ program with the results presented in Tables C-XI and C-XII used as inputs. The equations are in the following forms:

$$P_{K/H} = P_{max} \left(1 - \exp(-b(mv/A - k)^{n})\right) \quad \text{D-1}$$

where m is in kilograms, v in metres/sec, and A in square centimetres;

$$P_{cutoff} = P'_{max}\left(1 - \exp(-b' (1 + \log_{10}m - k')^{n'})\right) \quad \text{D-2}$$

where m is in grains.

Equation D-1 is used to compute conditional kill probability unless it is greater than Equation D-2; if so, Equation D-2 is used.

The average presented area, A, is expressed as a function of the mass:

$$A = k\, m^{2/3} \quad \text{D-3}$$

where k is a shape factor which depends on fragment density and geometry. The fragments produced by a steel plate attacked by the XM70 mine are nearly random in shape, and $k = 57.98\ cm^2/kg^{2/3}$.

Table D-I lists the coefficients for Equations D-1 and D-2 for both the V500 and V600 ammunition. The minimum mass, below which the $P_{K/H}$ is always zero, is 0.06 gm for the V500 ammunition and 0.19 gm for the V600 ammunition.

Table D-I

Ammo	P_{max}	k	b	n	P_{max}	k'	b	n'
V500	.832	1.2	.1541	1.3032	.838	0	.006963	5.2472
V600	.793	1.6	.1258	1.3492	.803	0	.003227	5.6526

DISTRIBUTION LIST

No. of Copies	Organization
12	Commander Defense Documentation Center ATTN: DDC-TCA Cameron Station Alexandria, VA 22314
1	Office Secretary of Defense The Pentagon ATTN: Mr. R. Thorkildson Washington, DC 20301
1	Director Defense Advanced Research Projects Agency 1400 Wilson Blvd Arlington, VA 22209
1	Commander U.S. Army Materiel Development and Readiness Command ATTN: DRCDMA-ST 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander U.S. Army Materiel Development and Readiness Command ATTN: DRCCP 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander U.S. Army Materiel Development and Readiness Command ATTN: DRCDL 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander U.S. Army Materiel Development and Readiness Command ATTN: DRCMA 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander U.S. Army Materiel Development and Readiness Command ATTN: DRCLDC, T. Shirata 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander U.S. Army Materiel Development and Readiness Command ATTN: DRCGS-L 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander U.S. Army Materiel Development and Readiness Command ATTN: DRCPA-S 5001 Eisenhower Avenue Alexandria, VA 22333
3	Commander U.S. Army Materiel Development and Readiness Command ATTN: DECBSI, COL C.J.Gearin DRC-BWI DRCDMD, MG Ira A. Hunt 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander U.S. Army Materiel Development and Readiness Command ATTN: DRCQA 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander U.S. Army Aviation R&D Cmd ATTN: DRSAV-E 12th and Spruce Streets St. Louis, MO 63166

DISTRIBUTION LIST

No. of Copies	Organization
1	Director US Army Air Mobility Research and Development Laboratory Ames Research Center ATTN: SAVDL-AS, Dr. R. S. Dunn Moffett Field, CA 94035
2	Commander US Army Electronics Command ATTN: DRSEL-RD DELSD-EM, C. Goldy Fort Monmouth, NJ 07703
2	Commander US Army Communications/ADP Laboratory ATTN: DRSEL-NL-RH Dr. F. Reder Mr. John Walker Fort Monmouth, NJ 07703
1	Commander Combat Surveillance and Target Acquisition Lab ATTN: DRSEL-CT-D Mr. Vincent Kublin Fort Monmouth, NJ 07703
1	Commander US Army Night Vision Lab ATTN: DRSEL-NV-VI Ms. Lou Ann Obert Fort Belvoir, VA 22060
2	Commander US Army Missile Research and Development Command ATTN: DRDMI-R DRDMI-C Redstone Arsenal, AL 35809
5	Commander US Army Tank Automotive Research & Development Command ATTN: DRDTA-RWL DRDTA, GEN Decker Warren, MI 48090
3	Commander US Army Mobility Equipment Research & Development Cmd ATTN: Tech Docu Cen, Bldg 315 DRSME-RZT DRXSB-O, Jerry Dean Fort Belvoir, VA 22060
1	Director Applied Technology Laboratory US Army Research and Technology Laboratories (AVRADCOM) ATTN: DAVDL-EU-MOS (VAT) Fort Eustis, VA 23604
1	Commander US Army Mobility Equipment Command 4300 Goodfellow Boulevard St. Louis, MO 63120
2	Commander US Army Armament Materiel Readiness Command ATTN: DRSAR-SAL Mr. Roger Powell DRSAR-LEP-L Tech Lib Rock Island, IL 61299

DISTRIBUTION LIST

No. of Copies	Organization
4	Commander US Army Armament Research and Development Command ATTN: DRDAR-TSS DRDAR-LCE-T, Ted Boxer DRDAR-LC, V. Guadagno DRDAR-LCS, J. Salomon Dover, NJ 07801
3	Commander US Army Armament Research and Development Command ATTN: SARPA-AD-D, Mr. E. Buchanan DRDAR-SC DRDAR-SER, CPT Lewis Dover, NJ 07801
1	Commander US Army Watervliet Arsenal Watervliet, NY 12189
1	Commander US Army Harry Diamond Labs ATTN: DRXDO-TI 2800 Powder Mill Road Adelphi, MD 20783
1	Director US Army Materials and Mechanics Research Center Watertown, MA 02172
1	Commander US Army Natick Research and Development Command ATTN: DRXRE, Dr. H. Sieling Natick, MA 01762
1	Commander U.S. Army Foreign Science & Technology Center ATTN: DRXST-MC-3, LT Ray Lutz 220 7th Street, NE Charlottesville, VA 22901
1	Project Manager STINGER ATTN: DRCPM-MP Redstone Arsenal, AL 35809
1	Project Manager Cannon Artillery Weapons Systems ATTN: DRCPM-CAWS Dover, NJ 07801
2	Project Manager M-60 Tank Development ATTN: DRCPM-M60TD DRDTA-R 28150 Dequindre Warren, MI 48090
1	Project Manager Fighting Vehicle Systems ATTN: DRCPM-FVS Warren, MI 48090
1	Project Manager Munition Production Base Modernization & Expansion ATTN: DRCPM-PBM Dover, NJ 07801
1	Project Manager 2.75-Inch Rocket System ATTN: DRCPM-RK Redstone Arsenal, AL 35809

DISTRIBUTION LIST

No. of Copies	Organization	No. of Copies	Organization
1	Project Manager DRAGON ATTN: DRCPM-MW Redstone Arsenal, AL 35809	1	Commander U.S. Army Combined Arms Combat Developments Activity ATTN: ATCA-CFD, CPT Coan Fort Leavenworth, KS 66027
1	Project Manager Improved TOW Vehicle ATTN: DRCPM-ITV Redstone Arsenal, AL 35809	1	Commander Combined Arms Center ATTN: ATZL-TDA-AD, MAJ Robertson Fort Leavenworth, KS 66027
1	Project Manager TOW ATTN: DRCPM-TO Redstone Arsenal, AL 35809	4	Commander U.S. Army Training and Doctrine Command ATTN: ATCD-DA, MAJ B. Robbins ATCD-C ATCD-CM-I, MAJ J. Wright ATCD-CM-A Fort Monroe, VA 23651
1	Project Manager HELLFIRE ATTN: DRCPM-HF Redstone Arsenal, AL 35809	2	Director U. S. Army TRADOC Systems Analysis Activity ATTN: ATAA-SL, Tech Library ATAA-T White Sands Missile Range, NM 88002
1	Project Manager Advanced Attack Helicopter ATTN: DRCPM-AAH, COL Broom St. Louis, MO 63166	1	Commander US Army Forces Command Fort McPherson, GA 30331
1	Project Manager Selected Ammunition ATTN: DRCPM-SA Dover, NJ 07801	3	Commander US Army Armor Center ATTN: ATZK-CD-SD ATZK-CD-CA ATZK-DCD, CPT Bryla Fort Knox, KY 40121
1	Project Manager XM-1 Tank System 28150 Dequindre Warren, MI 48090		
1	Asst Project Manager XM-1 Tank System ATTN: DRCPM-GCM-M Dover, NJ 07801		
1	Project Manager Army Gun Air Defense System ATTN: DRCPM-ARGADS Dover, NJ 07801		

DISTRIBUTION LIST

No. of Copies	Organization
1	Commander US Army Infantry Center ATTN: ATZB-CD-CS, (LTC Merlin Darling) Fort Benning, GA 31905
2	Manager Defense Logistics Studies Information Exchange US Army Logistics Management Center ATTN: Mr. L. Scarbrough Fort Lee, VA 23801
1	Commander US Army Engineer School ATTN: ATSE-CDC, (Mr. Thomas Montgomery Fort Belvoir, VA 22060
1	Commander US Army Field Artillery School ATTN: ATSF-G-OP Fort Sill, OK 73505
2	Commandant US Army Field Artillery Center ATTN: ATSF-CA ATSF-CD-W (L. Minton) Fort Sill, OK 73503
1	Commandant US Army Infantry School ATTN: ATSH-B (MAJ Best) Fort Benning, GA 31905
1	Commander Airborne Corps ATTN: AFZA-DPT-T (Mr. Robert L. Rice) Fort Bragg, NC 28307

No. of Copies	Organization
3	Headquarters (SGRD-RO/LTC M. H. Wood) (MAJ J. D. LeMothe) (COL E. L. Buescher) Washington, D. C. 20314
1	HQDA (DAMO-ZA) WASH DC 20310
1	HQDA (DAMA-ZA) WASH DC 20310
1	HQDA DAMO-RQD (LTC Richard Johnson) Pentagon Washington, DC 20310
1	Commandant Command and General Staff College ATTN: COL Boyd, Department of Tactics Fort Leavenworth, KS 66027
1	Commander Concepts Analysis Agency 8120 Woodmont Avenue Bethesda, MD 20014
1	US Army Engineer Waterway Experimental Station ATTN: Mr. David Coltharp P.O. Box 631 Vicksburg, MS 39180
1	Commander US Army Engineer Topographic Laboratories Fort Belvoir, VA 22060

DISTRIBUTION LIST

No. of Copies	Organization
1	Commander 7th Infantry Division and Fort Ord ATTN: MG Robert L. Kirwan Fort Ord, CA 93941
1	US Commander Berlin and US Army Berlin ATTN: AEBA-GC-O, LTC Vernon E. Ebert APO New York 09742
1	Commander US Army Europe APO New York 09403
1	Commander Naval Surface Weapons Center ATTN: Code DG-20 Morley Shamblen Dahlgren, VA 22448
1	Commander Naval Surface Weapons Center Silver Spring, MD 20910
2	Commander US Naval Weapons Center ATTN: Mr. Mel Keith Tech Library China Lake, CA 93555
1	Commander US Naval Research Laboratory Washington, DC 20375
1	Commander US Naval Ordnance Station Indian Head, MD 20640
1	Commander Marine Corps Development and Education Command ATTN: LTC C.S. Delgrosso Plans & Studies Div. Quantico, VA 22134

No. of Copies	Organization
1	Commander Marine Corps Development and Education Command ATTN: CPT Robert Clydesdale,III Firepower Division Quantico, VA 22314
1	Commander US Marine Corps ATTN: Code OTTU-12 MAJ Michael Janay Washington, DC 20380
1	AFSC Andrews AFB Washington, DC 20331
1	AFAL (MAJ R. Gilman) Eglin AFB, FL 32542
2	AFATL/DLYW (W.D.Thomas,J.Flint) Eglin AFB, FL 32542
1	AFWL Kirtland AFB, NM 87117

Aberdeen Proving Ground

Marine Corps Ln Ofc
Dir, USAMSAA
ATTN: DRXSY, Dr. Sperrazza
DRXSY-GA
DRXSY-DI
Dir, USAHEL
ATTN: DRXHE-SPG, Mrs. Thein
Dir, CSL, ARRADCOM, EA
ATTN: DRDAR-CLV, E. Enquist
DRDAR-ACW, A. Flatau
PM, Smoke/Obscurants
ATTN: DRCPM-SMK,
COL Shelton